Studies of Viscous, Kinetic and Transport Effects in ICF Target Dynamics

R. J. Mason

R. C. Kirkpatrick and R. J. Faehl

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Outline

- **We describe the ePLAS model used for our calculations.**

- **We compare shock development with *artificial* and *real* viscosity in Cartesian and spherical implosive flows.**

- **We examine self-consistent *E*- and *B*-field effects.**

- **We show that the real viscosity can spread small scale shocks affecting their collapse dynamics.**

The RAC e-PLAS code

Features:

2-D, fluid ions and electrons with inertia, *artificial* or *real* ion viscosity, electron & ion thermal conductivity, ion & electron thermal coupling, bremmstrahlung, external piston velocity drive, *Implicit Moment E-* & *B*-fields, relativistic electron corrections.

Special Capabilities:

- **High target densities (>10^{25} e^-/cm^3) and vacuum regions.**
- **No Δt restraint from $\omega_p \Delta t < 1$, allowing *large scale problems*.**
- **Alternate ion and electron particle modelling (fluids here).**

Richtmeyer & Morton used artificial viscosity to fix shock thicknesses "at about (3-4)Δr"

- P. 312: … "with ordinary" (*real)* "viscosity, in which the stress is proportional to the rate of sheer, and which is therefore represented by linear terms in the differential equations, the thickness of the transition layer varies with the shock strength, approaching zero for a very strong shock and infinity for a very weak one. But we wish the thickness to be about the same—namely, about (3-4)Δr– for all shocks, and we therefore" (artificially) "add *quadratic* terms to the differential equation ; this is equivalent to using a small viscosity coefficient for weak shocks and a large on for strong shocks. It will be shown below that we achieve a thickness independent of the shock strength."

A *real* viscous pressure is more fundamental

$Q_{qz} = -K_{qz}\partial/\partial z(u_i)$, spreads u_i with $\partial u_i/\partial t = -\partial/\partial z(Q_{qz})/(n_i m_i)$, in which $K_{qz} = (m_i n_i v_{th} \Lambda_{ii})$, $\Lambda_{ii} = v_{th}/\nu_{ii}$, and $\nu_{ii} \sim n_i/T_i^{3/2}$. (Here z is the axial direction in 2D problems.)

So, there is n_i independence in K_q, but as $T\uparrow$ we get $\nu_{ii}\downarrow\downarrow$.

Tenuous regions can heat readily, implying very broad viscous spreading of the flow.

We have chosen to "flux limit" such stress effects to multiple ($f \sim 20$) cells: $f\Delta z$.

Run parameters

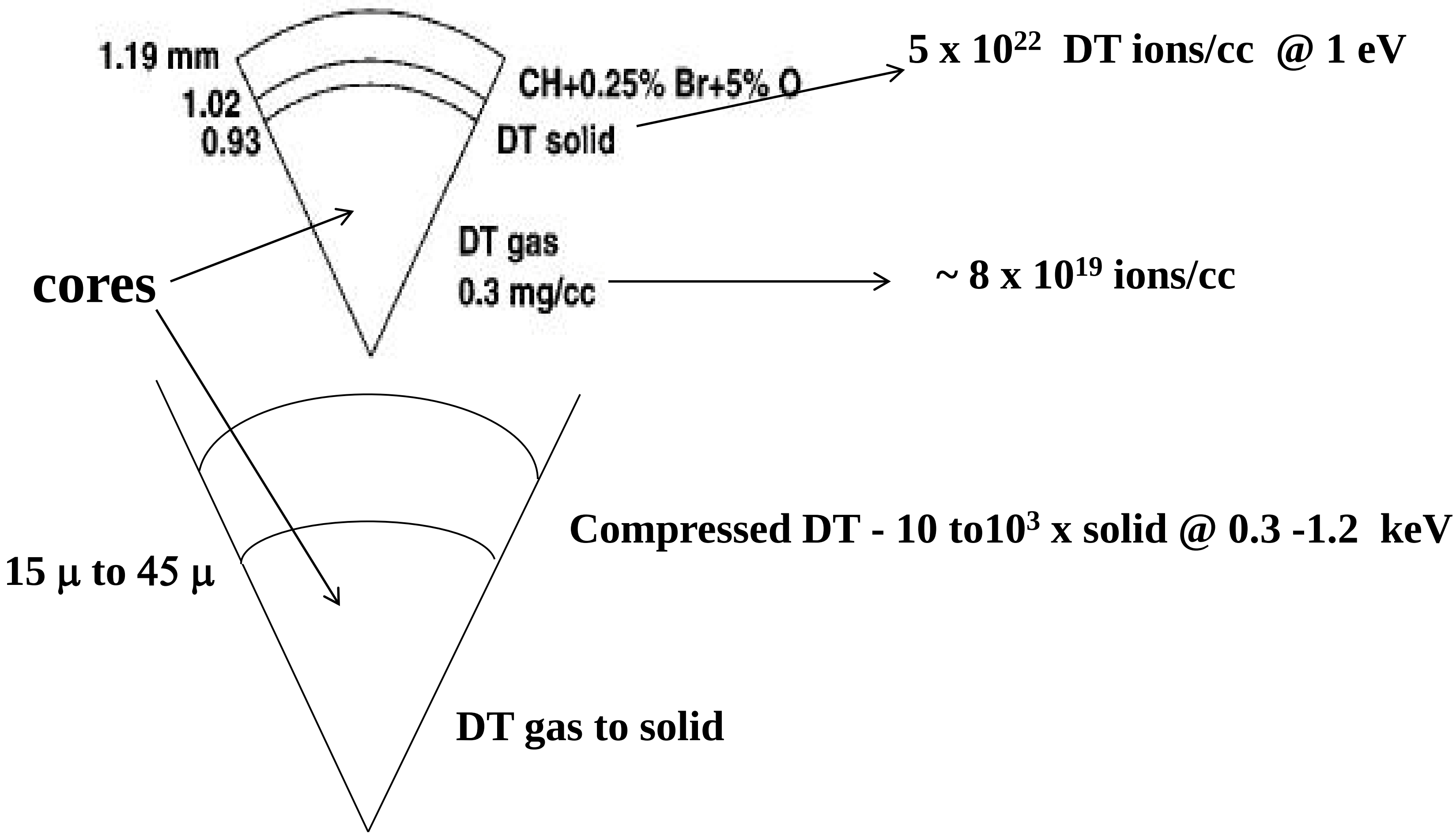
- **We will explore a 20-40 μm scale test region in Cartesian and spherical geometries.**

- **A DT ion plasma at 1.2 keV with fluid electrons evolves for up to 26 ps, producing a contact surface, shocks, and spherical convergence.**

- **Driving shell densities are from 5×10^{23} to 2×10^{25}/cc with voided "core" densities from to 7×10^{19} to 5×10^{22} /cc.**

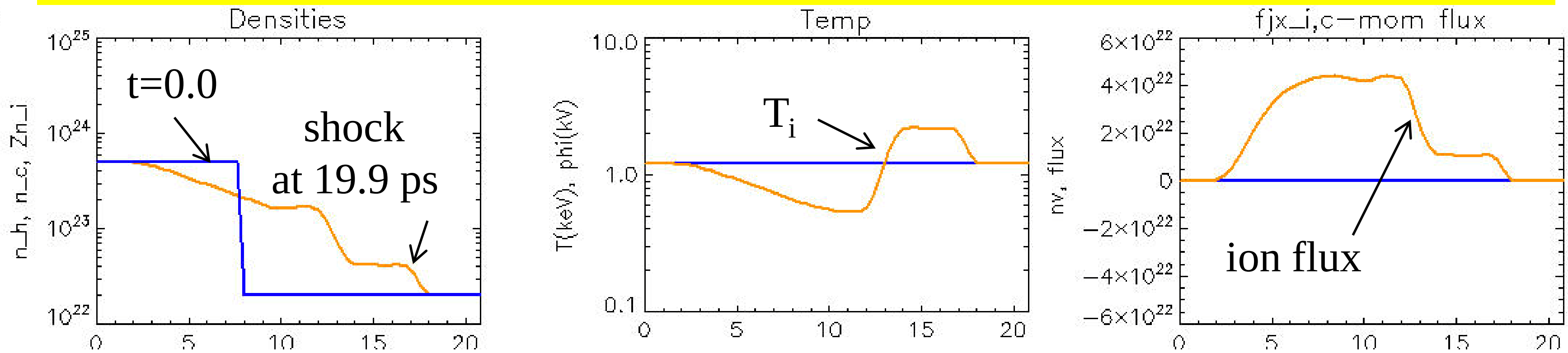
- **The mesh uses 50 to 100 cells for 2D cylindrical (spherical) simulations.**

Ultimately we will be interested in the core shock dynamics of NIF-like ICF targets

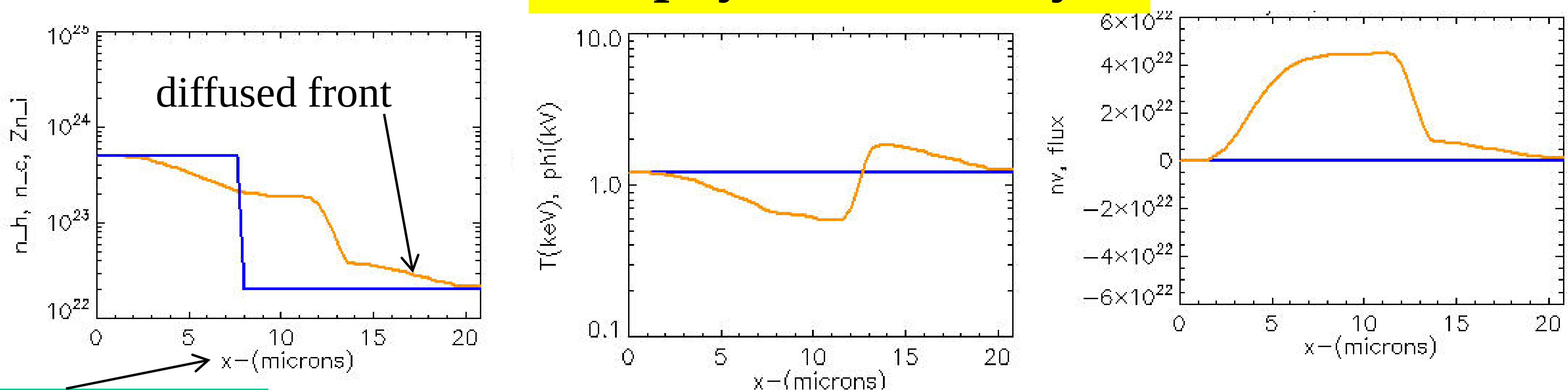


Real viscosity produces diffusing fronts instead of steep shocks in low density planar target voids

Conventional *artificial* viscosity for 1.2 kev drive – ions only



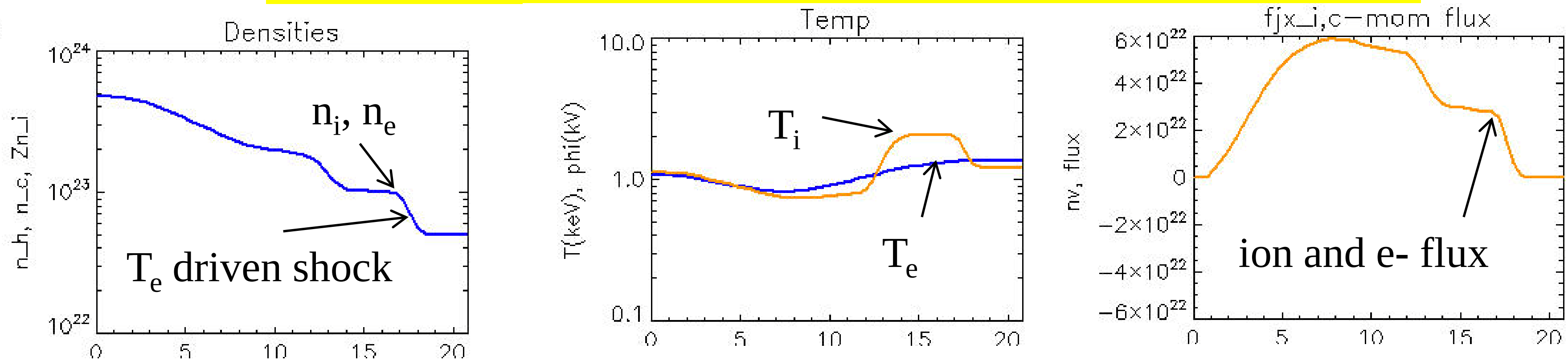
***real* physical viscosity**



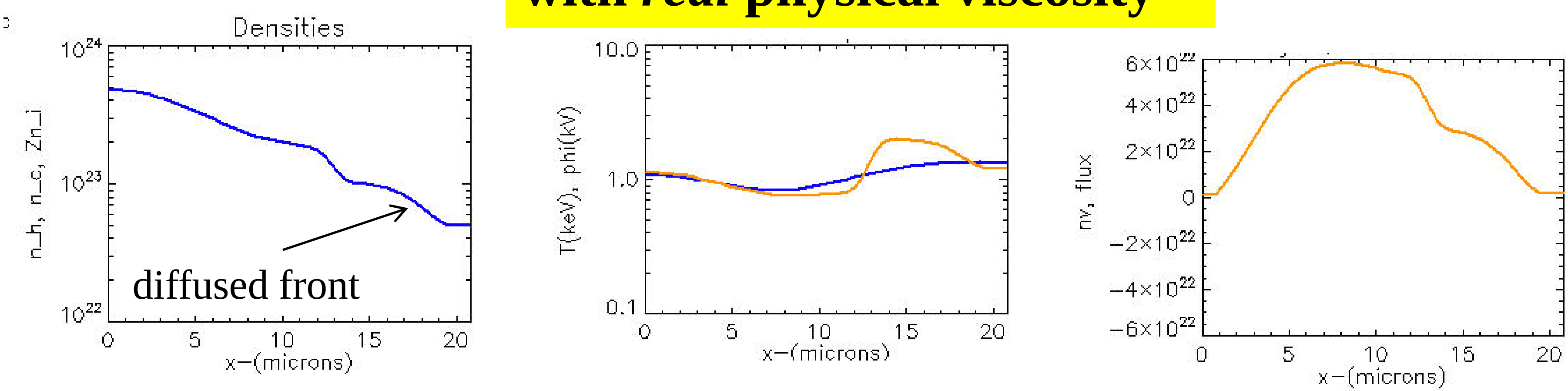
Cartesian geom

Such spreading with *real* viscosity continues when *E*-fields from e^- pressure are introduced

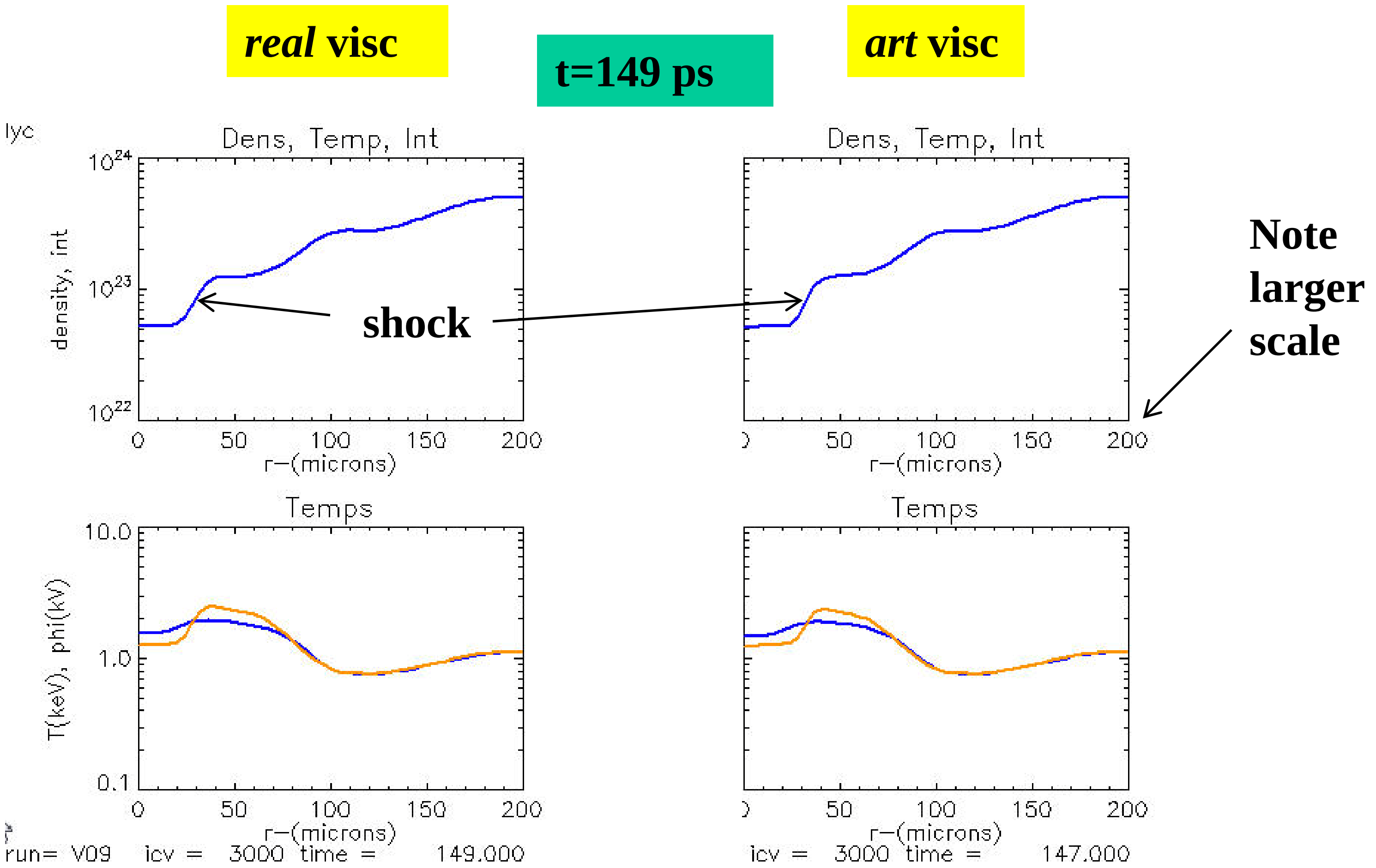
with conventional *artificial* viscosity at 17 ps



with *real* physical viscosity

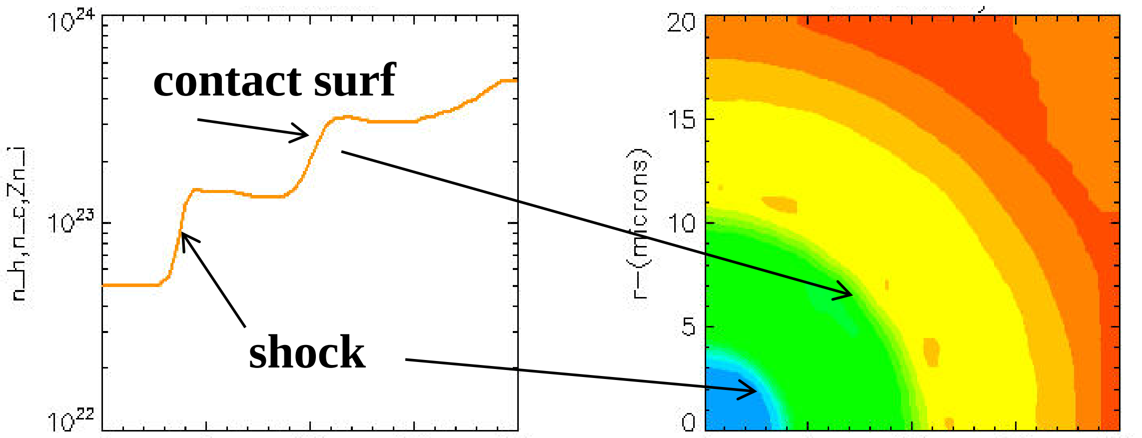


But with a *10 x larger flow scale* there is little viscous model effect on the shock structure

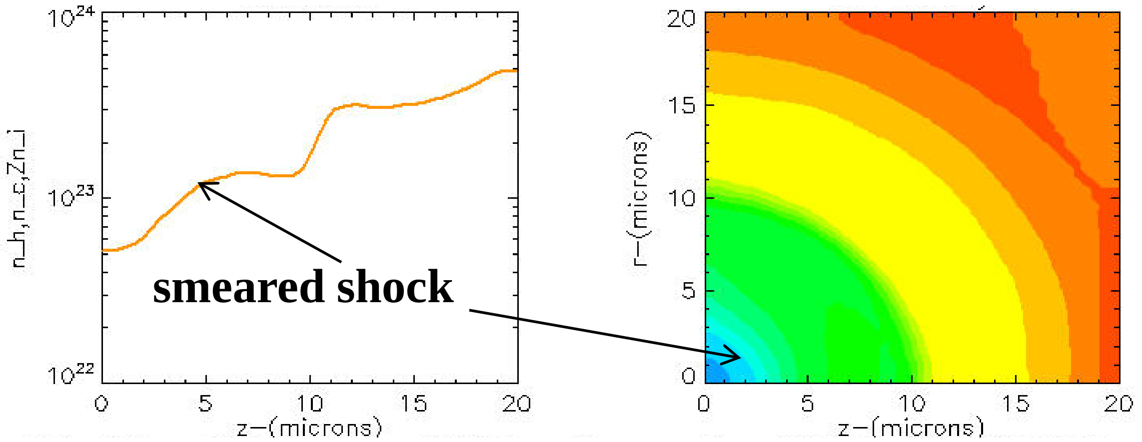


Spherical implosions show a similar *small scale* dependence on the viscosity model

***artificial* viscosity @ 9.3 ps**

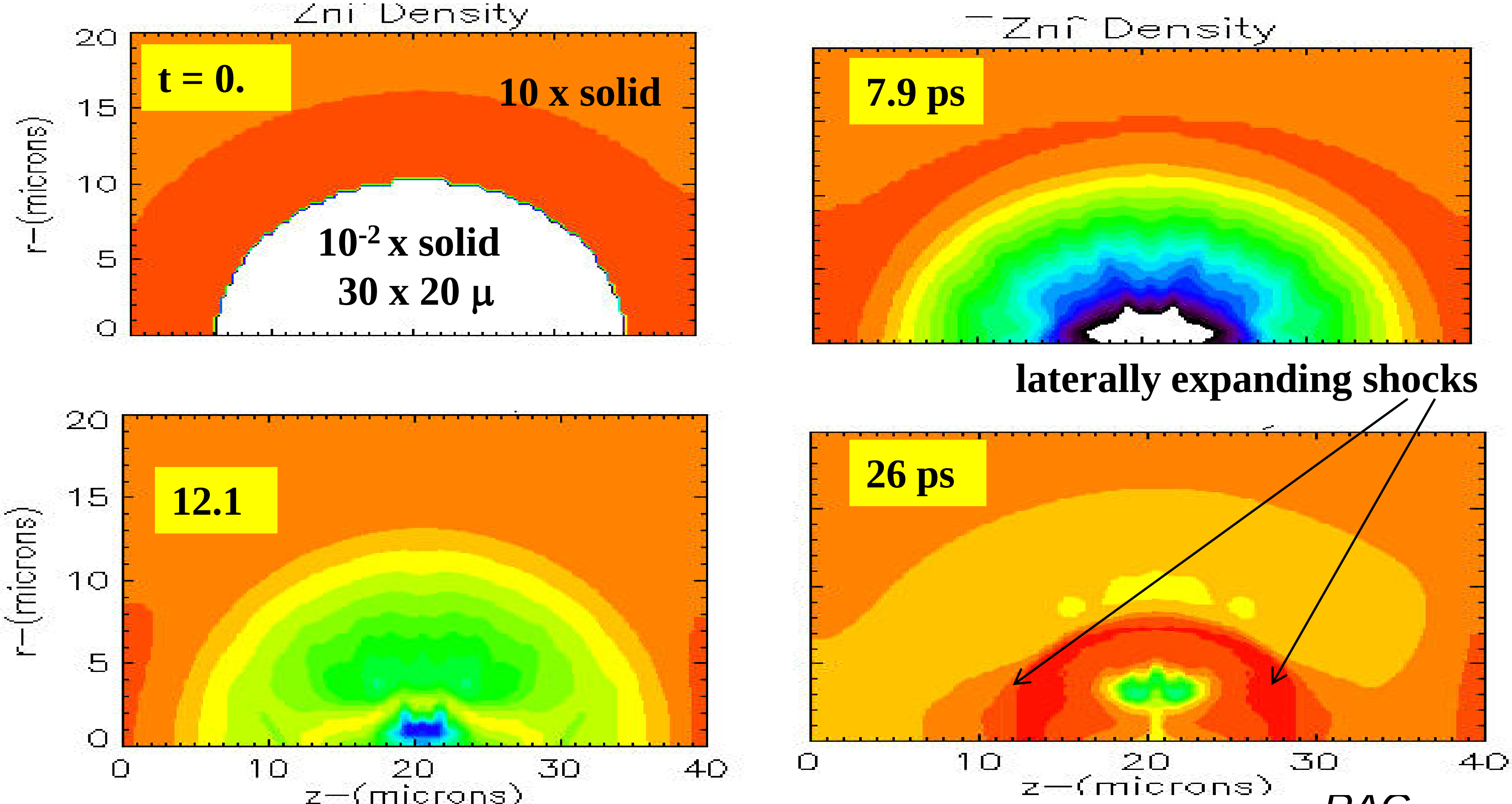


***real* viscosity**

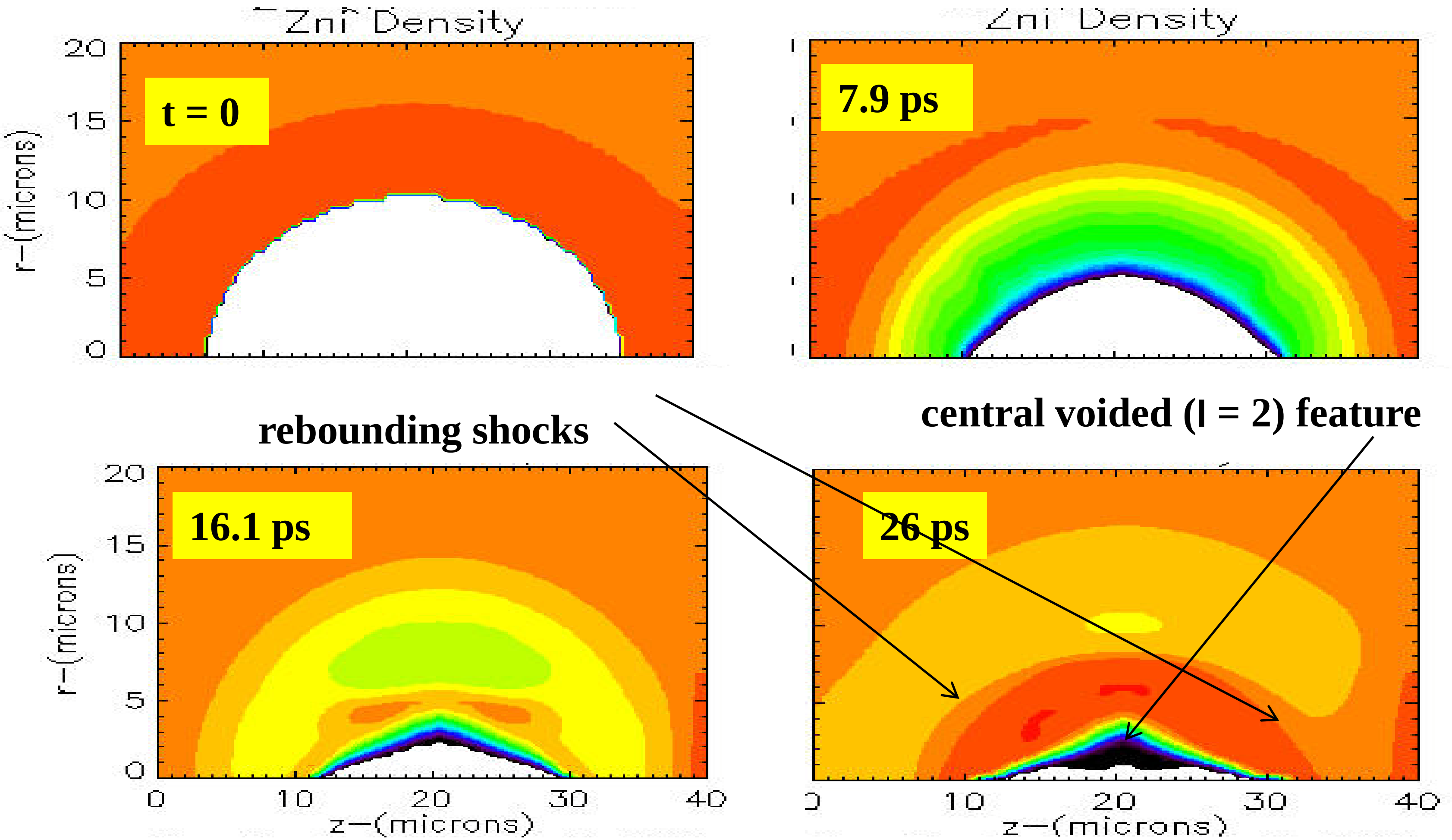


Elliptical DT target implosions show a strong viscosity dependence (here: for *artificial* visc)

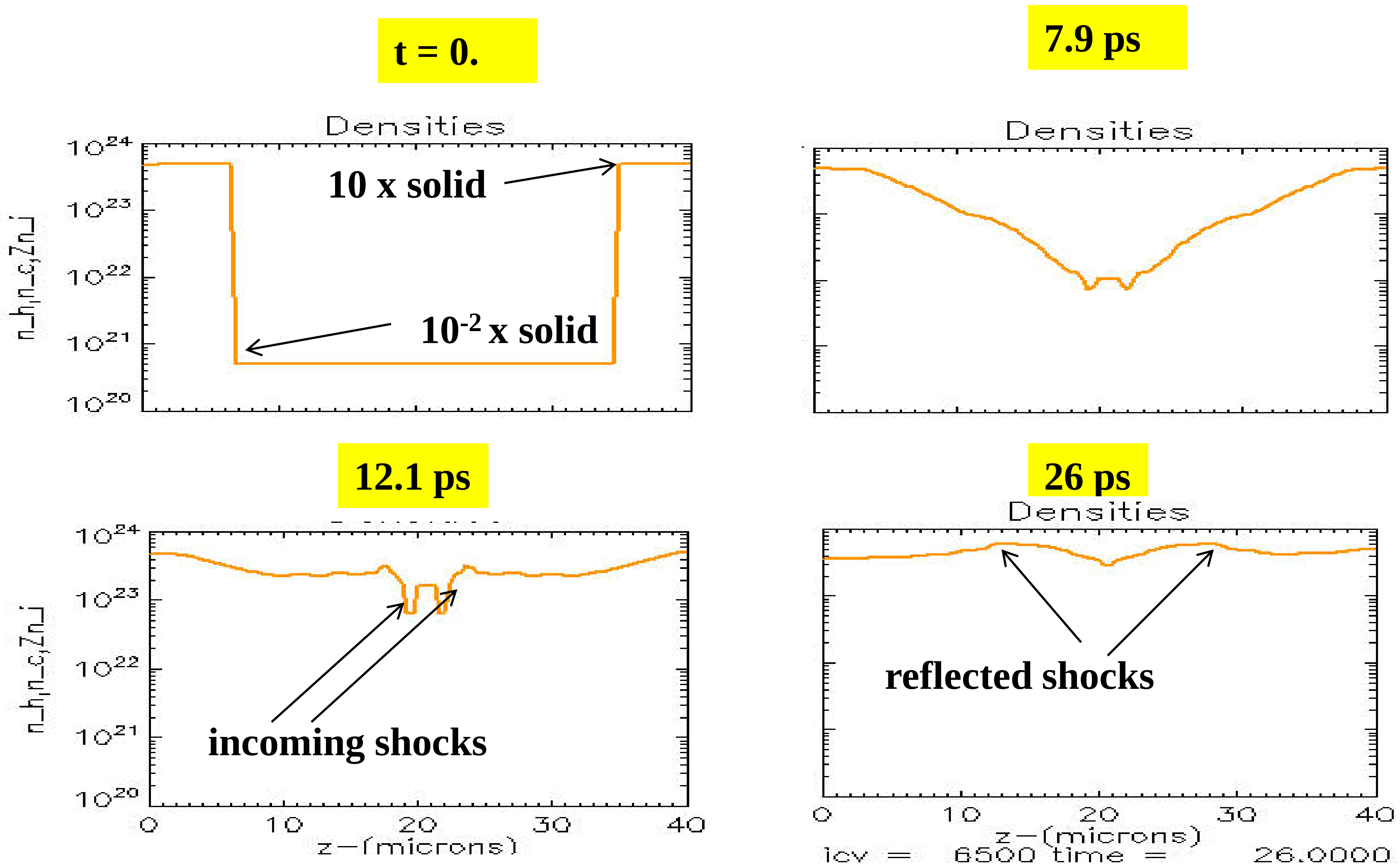
Initially T_i = 1.2 keV. Note the shocked ring development.



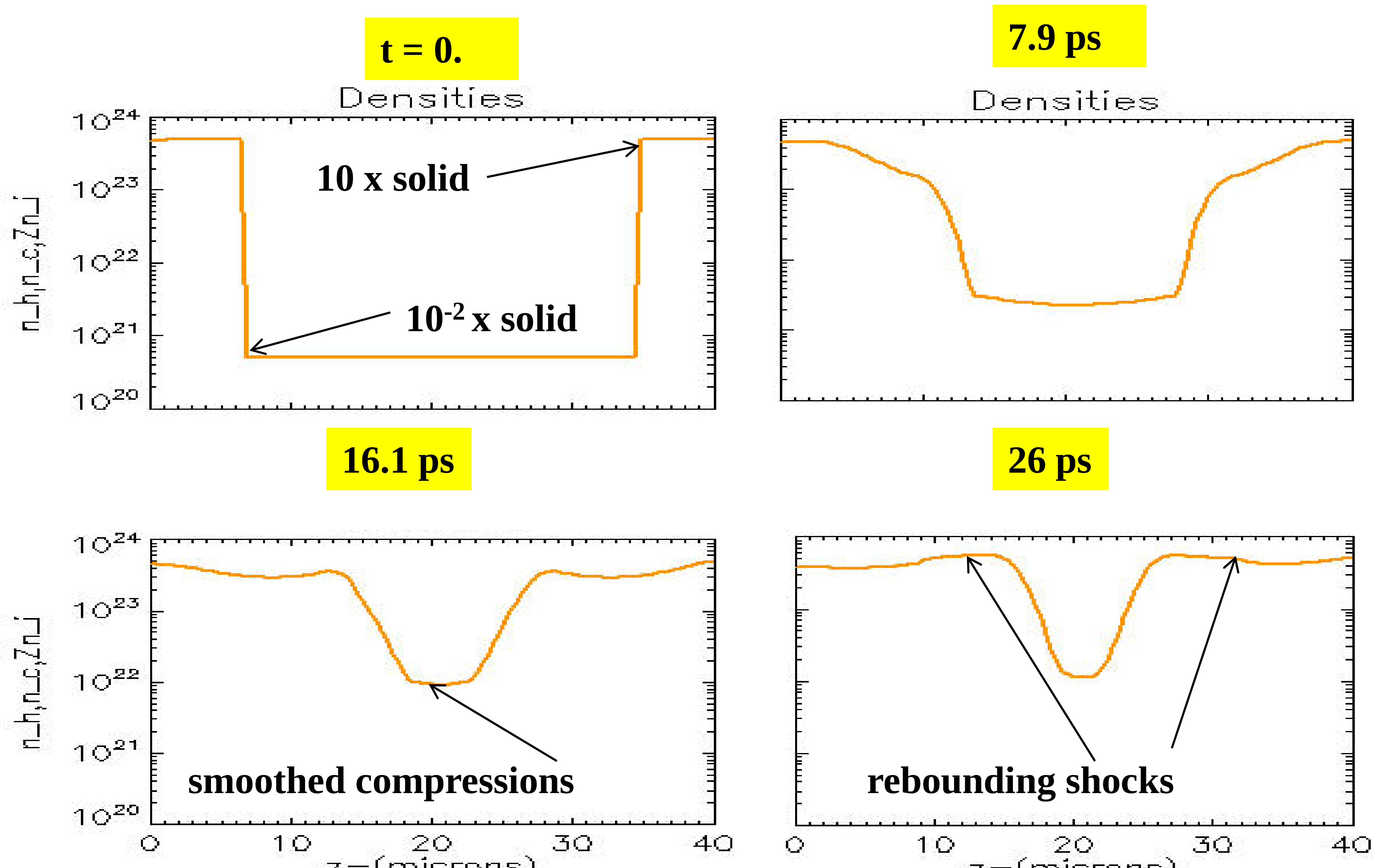
While with *real* viscosity, we see compression and an l = 2 central voided feature + shocks



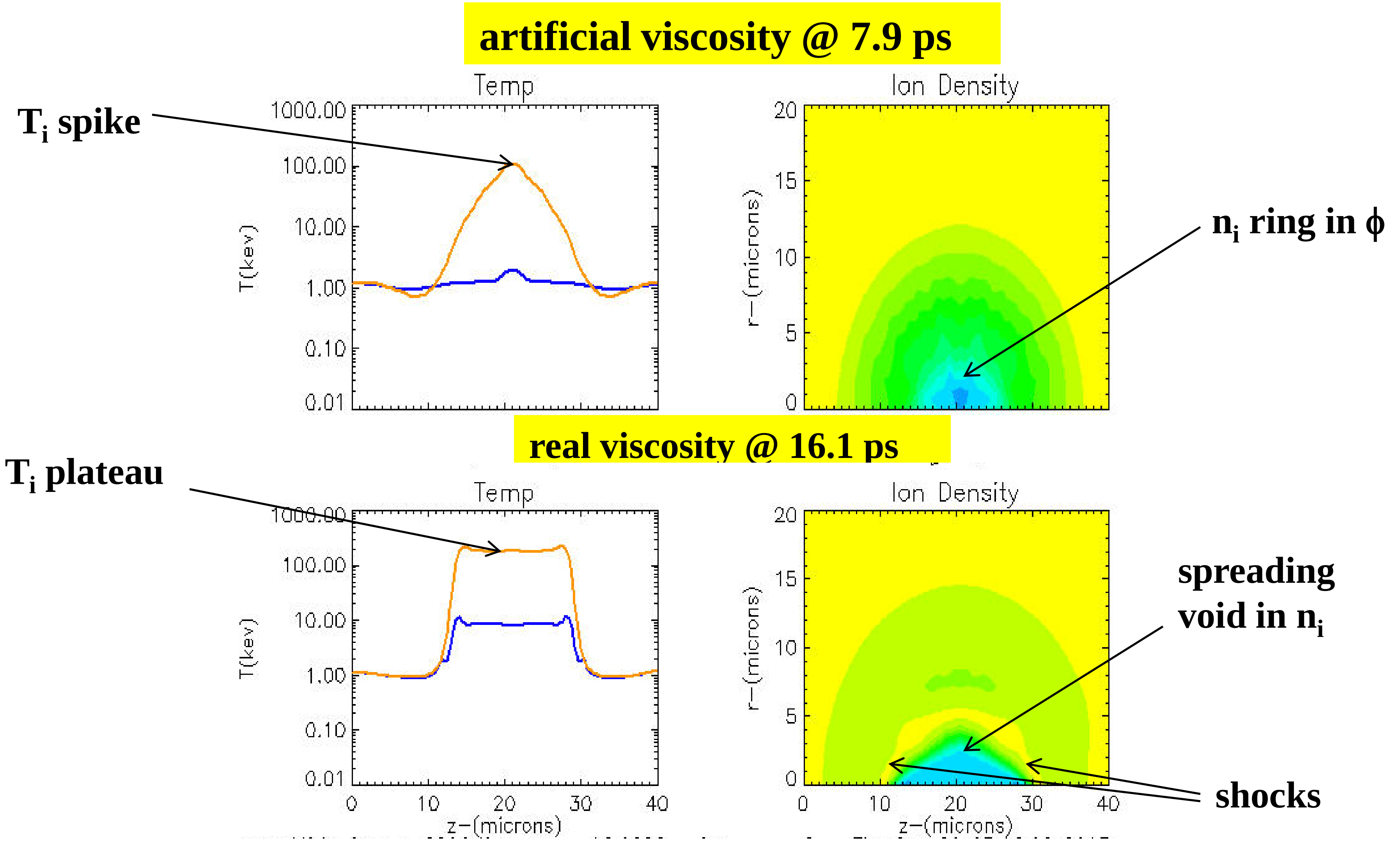
The associated *art* viscosity axial density profile shows shock convergence and rebound



Real viscosity also gives a smoother lower, central density profile at peak compression

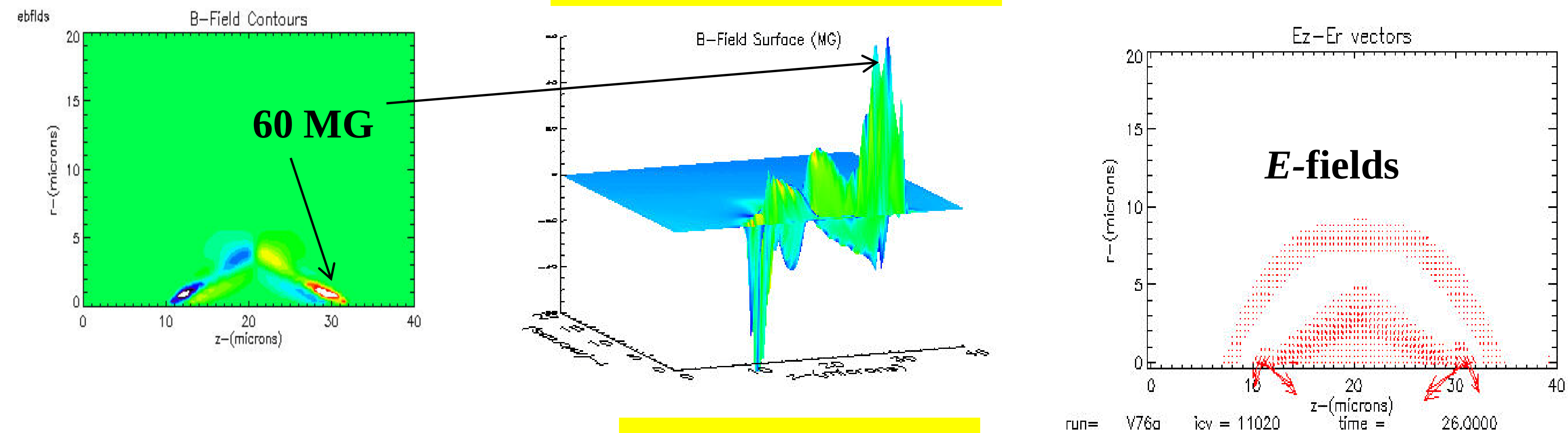


Art viscosity gives a spiked central temperature and density - with *real* visc these are smeared

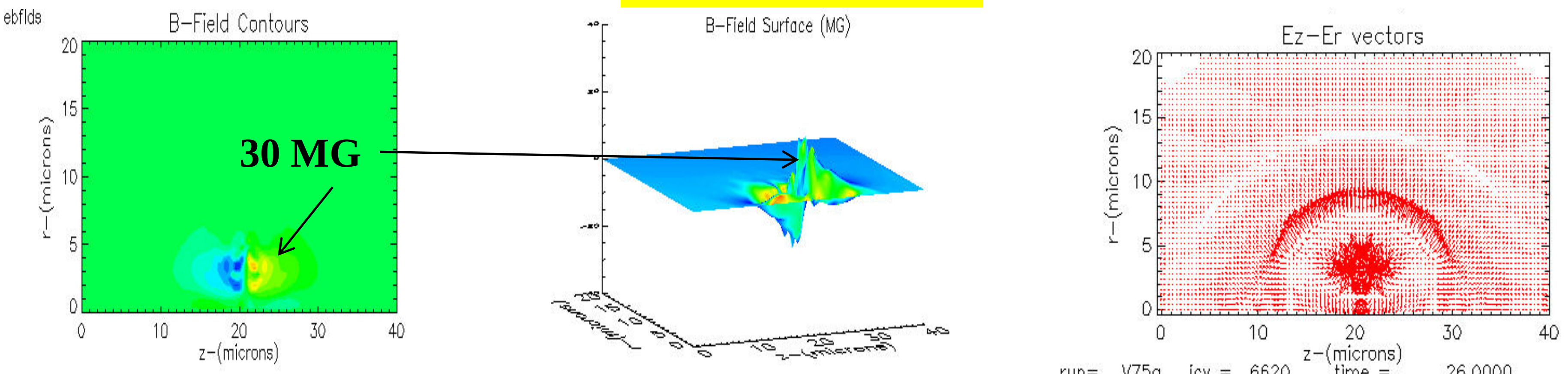


Central *B*-fields in the target core are twice as large with *real* viscosity

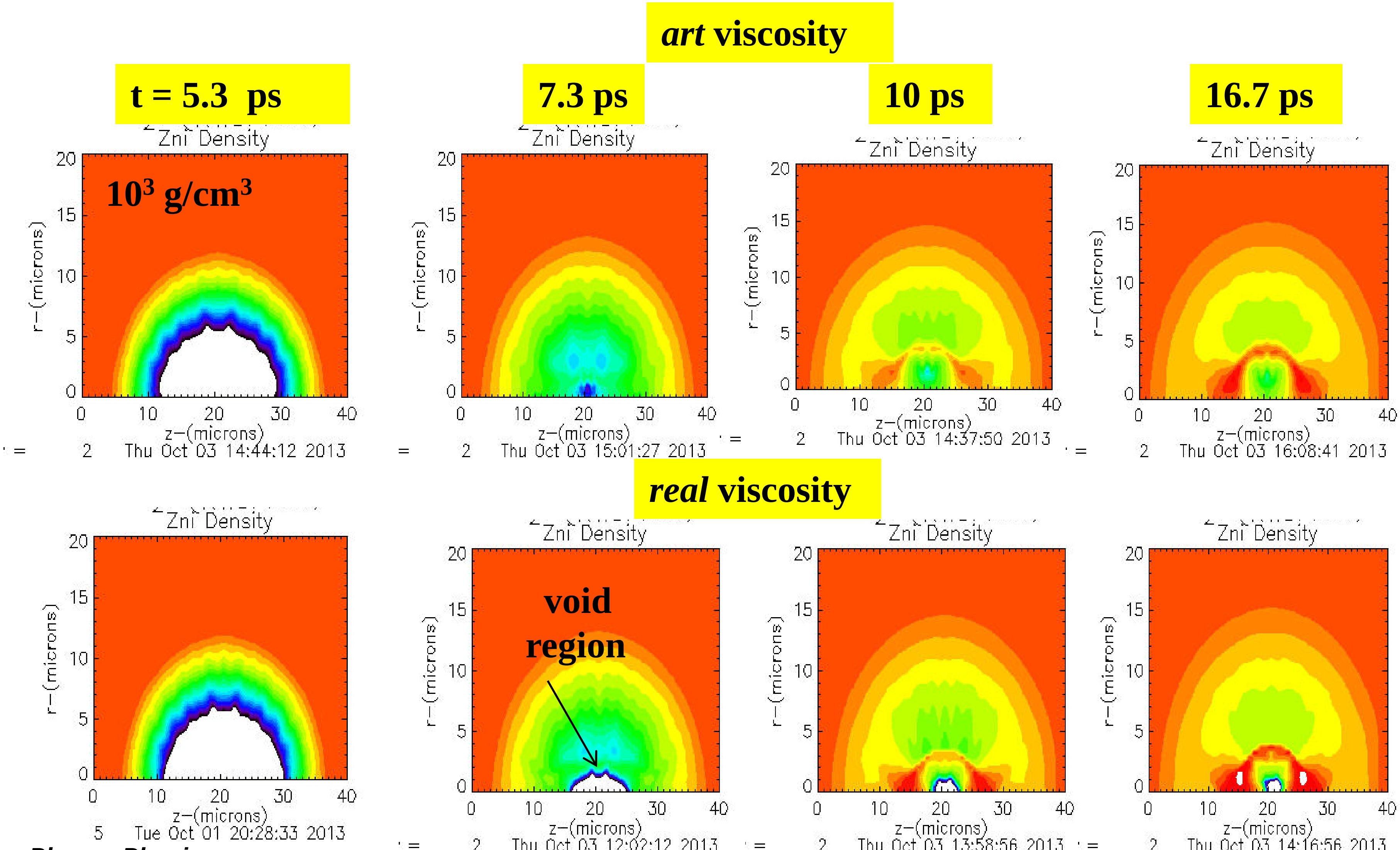
***real* viscosity @ 26 ps**



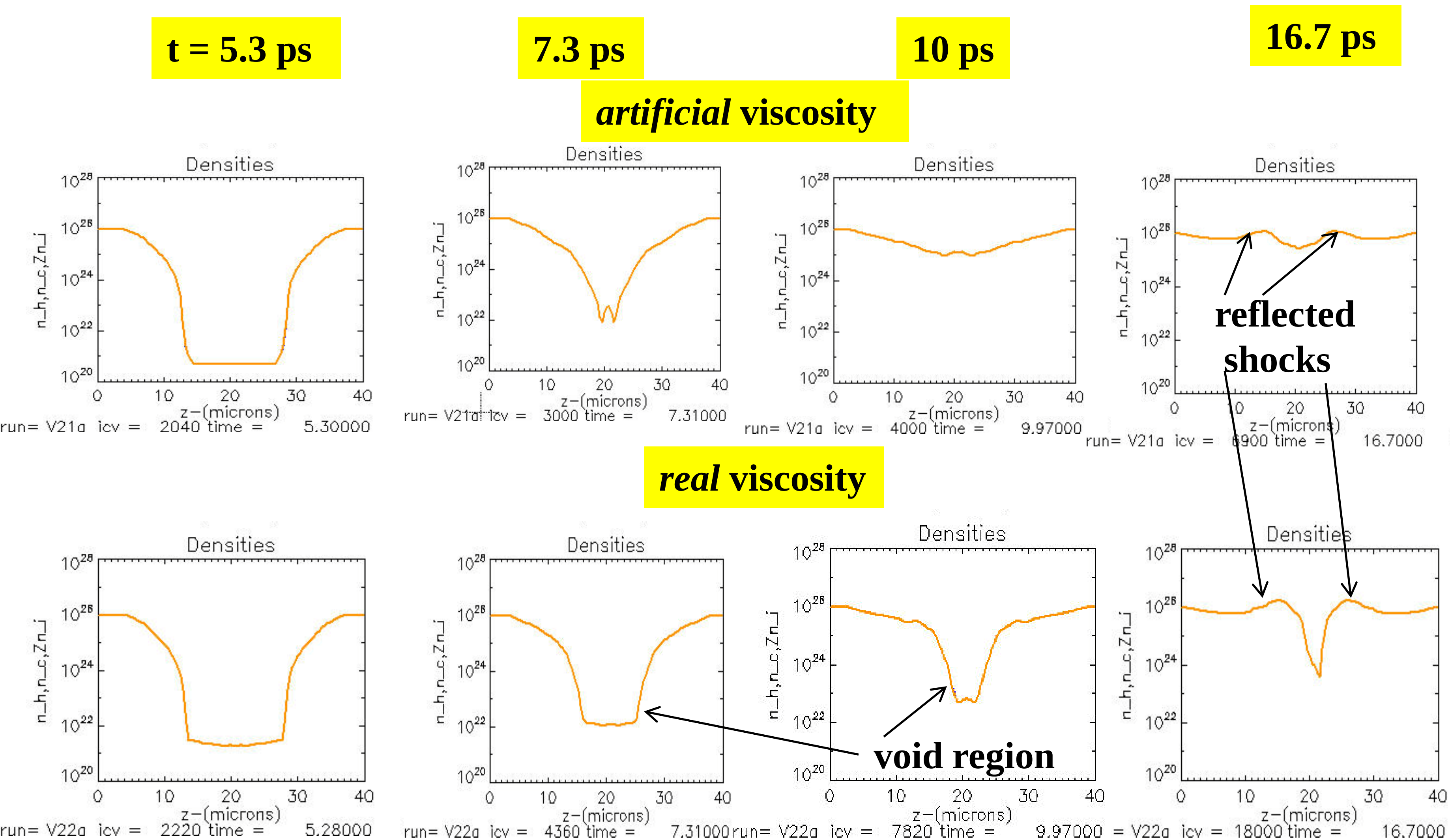
***artificial* viscosity**



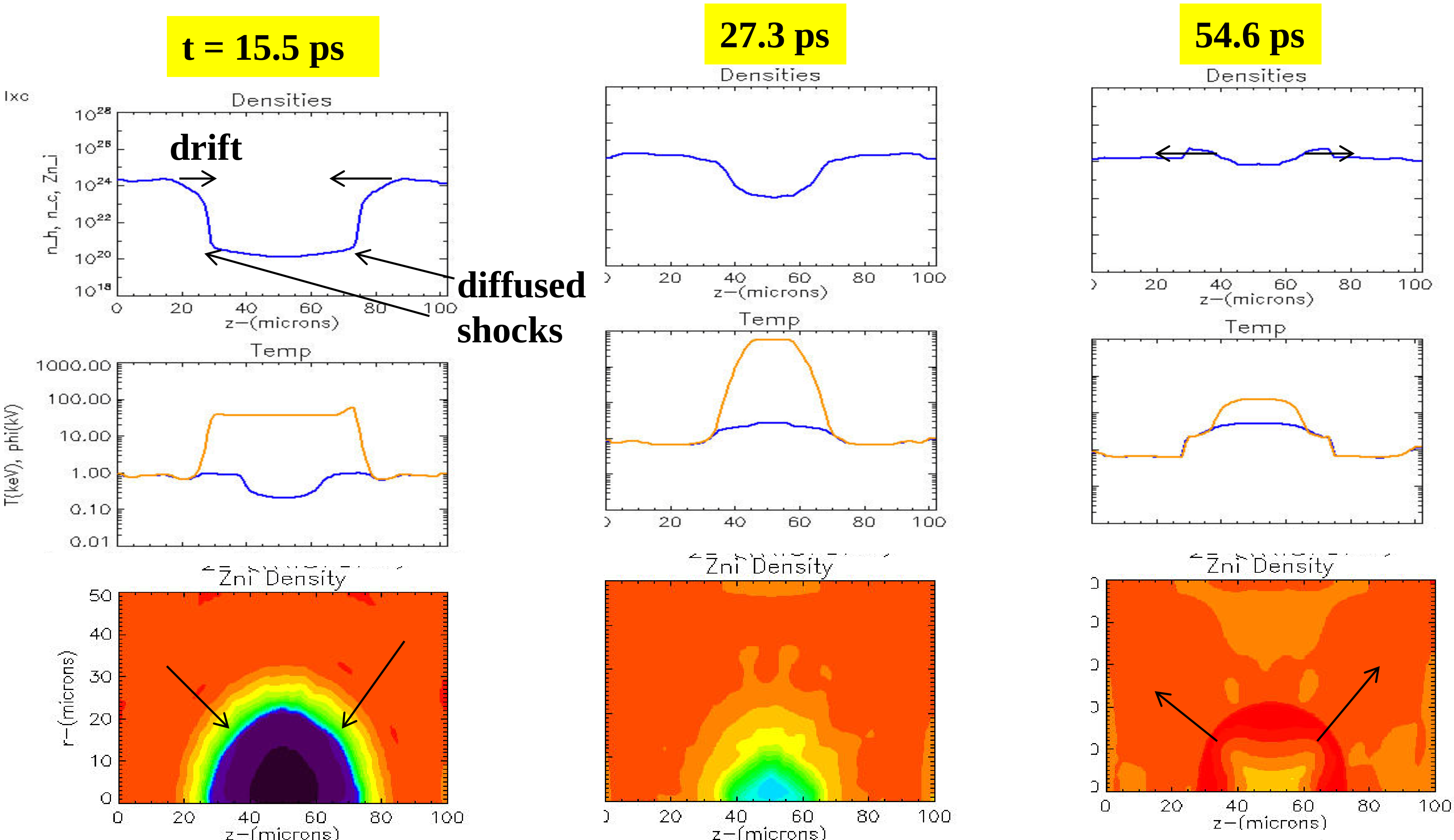
With imploding densities near 1000 g/cm^3 spherical core conditions depend on the viscous model



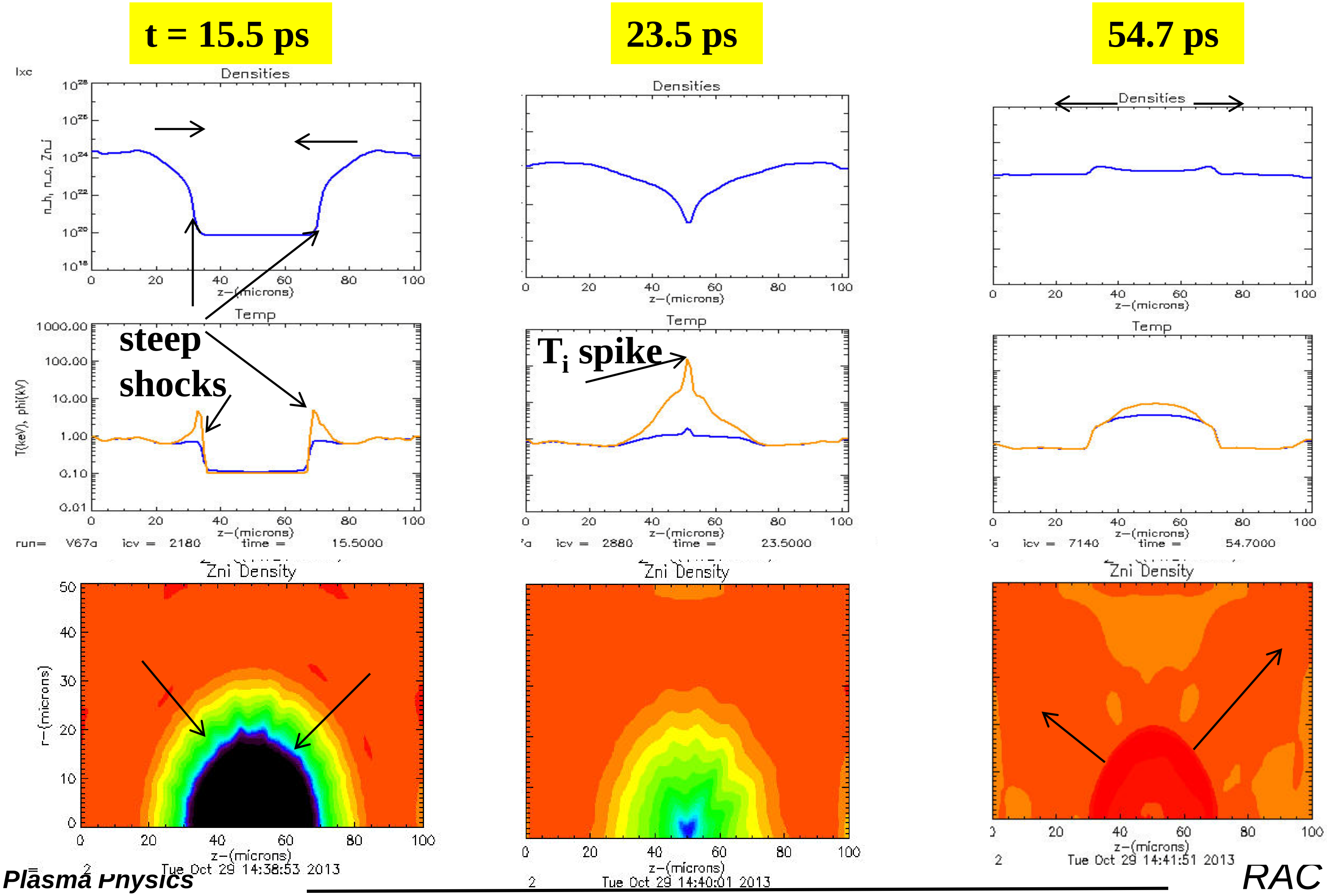
The corresponding axial densities evolve from the driving 1000 g/cm^3 densities as:



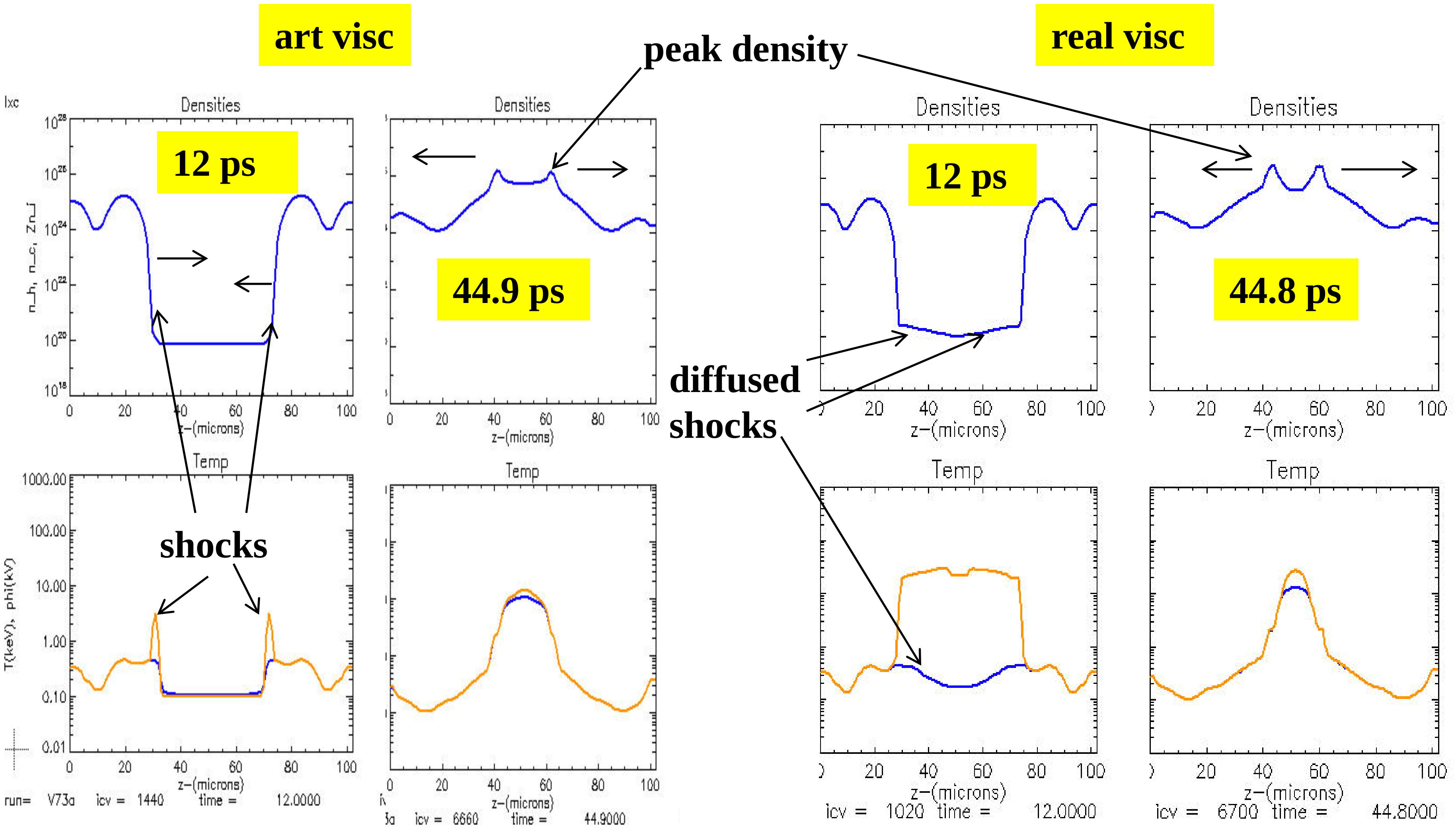
In NIF-like Implosions with initial inward shell drive *real* viscosity produces diffused shocks



While *art* viscosity gives traditional steep shocks

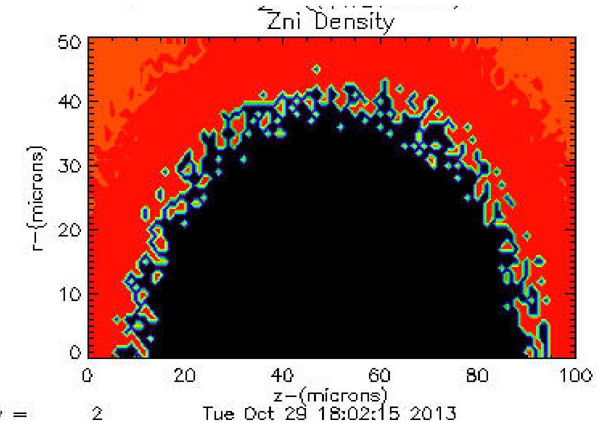


However, with a 350 eV shell and a 0.75 μ/ps piston <u>both</u> viscous models give ~1000 g/cc density peaks

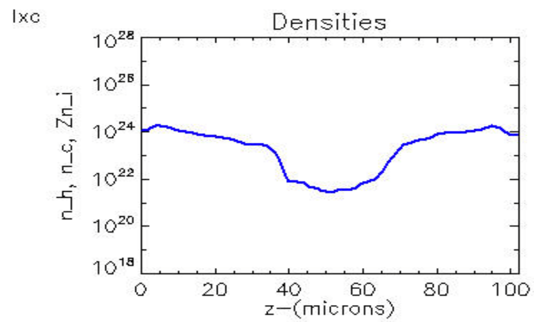


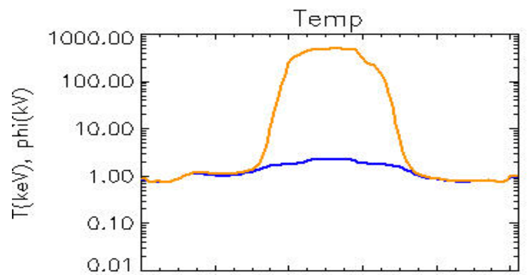
A rough inner shell surface doesn't appear to change the acquired "peak" conditions

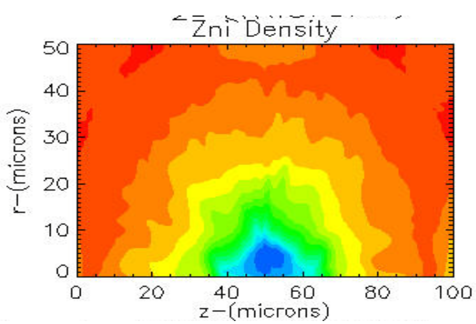
t=0
10μ surface perturbation



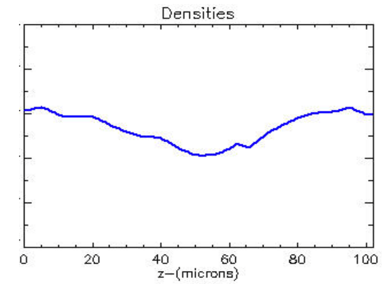
***real* visc, 25.5 ps**

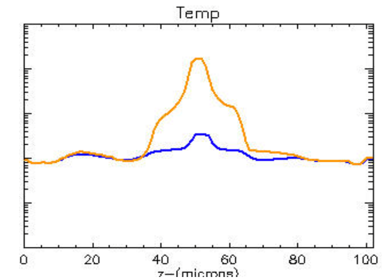


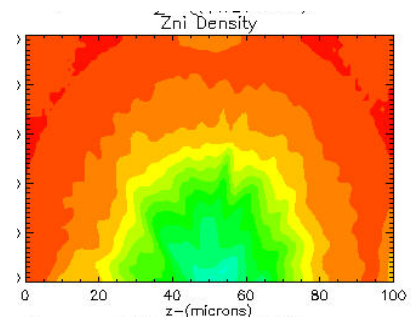




***art* visc, 21.8 ps**







Conclusions

- **Replacing the usual *artificial* viscosity with a *real* version can significantly alter small scale implosion dynamics, accessing some of the new physics that would be embodied in a kinetic treatment.**

- **2D spherical effects are readily accessed at minimal additional expense.**

- **General use of *artificial* viscosities may have lead overly optimistic predictions for NIF targets or, at least, inappropriate pulse shape tunings.**

Contact Us -

- eMail: rodmason01@msn.com

- ePLAS Code: http://www.researchapplicationscorp.com